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Selection and Evaluation of Thin Layer Drying Models for Microwave Drying of Mushroom

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Abstract

The effect of treatments on microwave drying characteristics of mushroom was investigated. The experiments were conducted on mushroom samples with mass of 100 g at different microwave powers. Mushroom samples 93,4%(±0,02) humidity on wet basis were dried in microwave oven with 180, 360, 540, 720 and 900W microwave powers until the humidity fell down to 9,27%(±0,06) on wet basis. In this research, the drying data were applied to eleven different mathematical models, namely, Newton, Page, Henderson and Pabis, Midilli-Kucuk, Wang and Singh, Two Term, Two Term Exponential, Diffusion Approach, Weibull Distribution, Logistic and Alibas Equation Models. The performances of these models were compared according to the coefficient of determination (R^2), standard error of estimate (SEE) and residual sum of square (RSS), between the observed and predicted moisture ratios. The results showed that Weibull Distribution and Alibaş models were found the better to describe the drying of mushroom samples.

Keywords: Microwave, drying, mushroom, mathematical modeling

Özet

Mantarın mikrodalga ile kurutulması üzerine yapılan kuruma davranışının etkileri araştırılmıştır. Denemeler, 100 g ağırlığına sahip mantar örnekleriyle farklı mikrodalga güçlerinde gerçekleştirilmiştir. Yaş baza gore %93,4 (±0,02) ilk nem içeriğine sahip mantar örnekleri yaş baza göre %9,27 (±0,06) son nem içeriğine gelene kadar mikrodalga fırında 180, 360, 540, 720 ve 900W mikrodalga güçlerinde kurutulmuştur. Bu çalışmada, Newton, Page, Henderson ve Pabis, Midilli-Kucuk, Wang ve Singh, İki terimli, İki terimli üssel, Difüzyon yaklaşımı, Weibull Distribution, Logistic ve Alibas Equation Models olmak üzere 11 tane model eşitlik uygulanmıştır. Bu modellerin performansları gözlemlenen ve tahmini nem oranları arasında belirtme katsayısı değeri (R^2), tahmini standart hatası (SEE) ve kalanların kareleri toplamına (RSS) göre karşılaştırılmıştır. Sonuçlar göstermiştir ki, diğer model eşitliklerle karşılaştırıldığında Weibull ve Alibaş Model eşitlikleri en iyi tahmini vermiştir.

Anahtar kelimeler: Mikrodalga, kurutma, mantar, matematiksel modelleme

Introduction

Mushrooms are non-green, eatable fungi. They are a great heterogeneous group having various shapes, sizes, appearance and edibility. Mushrooms are a good source of non-starchy carbohydrates, dietary fiber, protein, mineral and vitamins. Mushrooms are a seasonal and highly perishable crop and contain about 90% (w.b.) moisture. There are many methods for preservation and development of shelf life of mushrooms. The most common processes include canning, freezing and drying.

Microwave drying of foods and agricultural products takes advantage of the special heating behaviour of the microwave energy to the commodity. Some of the advantages of the microwave heating in drying of foods and agricultural products over the conventional drying methods are fast and volumetric heating**,** higher drying rate, short drying time, quality of the product, reduced energy consumption, cost savings (Mujumdar, 2000).

In recent years, microwave drying have being used widely as an alternative drying method for a wide variety of food products such as fruits, vegetables, snack foods and dairy products.

Several researchers investigated the drying kinetics of various agricultural products and they developed different mathematical models for describing the microwave and hot air drying characteristics such as Funebo and Ohlsson (1998) for apple and mushroom, Torringa *et al.* (2001) for mushroom.

The main purpose of the present work is to compare the developed mathematical models for drying of mushroom, to investigate moisture ratios of mushroom samples dried by microwave powers.

Material And Methods

Mushroom samples were used in this work and was purchased from a local market. The whole samples were stored at 4±0.5 ºC before experiments in order to slow down the respiration, physiological and chemical changes (Maskan, 2001). Before drying, mushroom samples were taken out of storage and 100 g samples were dried in an oven. The initial moisture content of the mushroom samples was determined as 93,4%(±0,02) (w.b.) using a standard methods by the drying oven at 105º C for 24 h (Soysal, 2004; Karaaslan & Tunçer, 2008). This drying procedure was replicated three times.

Drying experiments were performed in a domestic microwave oven (Arçelik MD-824 ,Turkey) with maximum output of 900W at 2450 MHz in the Department of Agricultural Machinery, Faculty of Agriculture, Suleyman Demirel University, Isparta, Turkey. A domestic microwave oven operating at 2450 MHz with a turntable was used throughout the experiments.

The extents of the microwave cavity were 210 mm by 340 mm by 340 mm. the microwave oven had the capability of operating at five different microwave output power levels: 180, 360, 540, 720 and 900W. The mushroom samples were uniformly spread on the turn-table inside the microwave cavity, for an even absorption of microwave energy. For the mass determination, a digital balance of 0.01 g accuracy (Sartorius GP3202, Germany) was used. Depending on the drying conditions, moisture loss was recorded at 1 min intervals during drying at the end of power-on time by removing the turn-table from the microwave, and periodically placing the sample, on the digital balance (Soysal et al, 2006). The data obtained was an average of these results.

To investigate the effect of microwave output power on moisture content and drying time, five microwave output powers, 180, 360, 540, 720 and 900 W were used for drying 100 g mushroom samples. Mushroom samples were dried until equilibrium moisture content (no weight change) was reached.

Mathematical modeling of drying curves

Drying curves were fitted with 11 thin layer drying models, namely, Newton, Page, Henderson and Pabis, Midilli-Kucuk, Wang and Singh, Two Term, Two Term Exponential, Diffusion Approach, Weibull Distribution, Logistic and Alibas Equation Models (Table 1). The moisture ratio and drying rate of broccoli were calculated using the following equation:

$$MR = \frac{M - M_e}{M_0 - M_e} \qquad (1)$$

where *MR*, *M*, M_0, M_e, are the moisture ratio, moisture content at any time, initial moisture content, equilibrium moisture content, respectively and t is drying time (min).

Statistical analysis

Statistical analysis and non-linear regression analysis were conducted in order to guess the parameters of the equation using Sigma Plot (scientific graph system, version 12.00, jardel). Regression results include coefficient of determination (R^2), standard error of estimate (SEE), and residual sum of square (RSS). R^2, SEE and RSS are the essential parameters for selecting the best model to define the drying curves of mushroom samples.

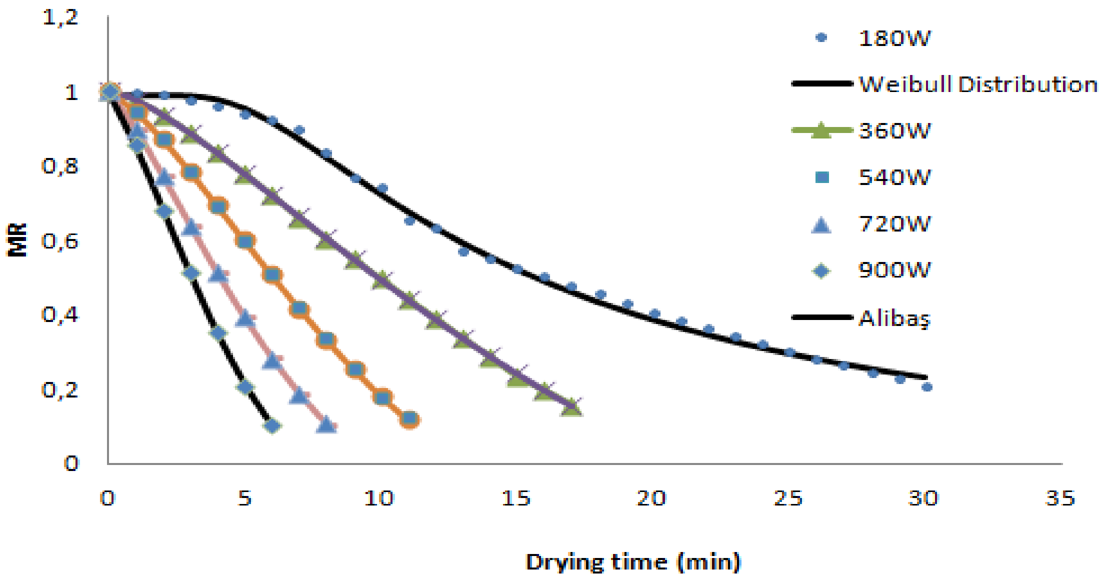

Figure 1. Variation of experimental and predicted moisture ratio by Weibull Distribution and Alibaş models with drying time at selected microwave output powers

Table 1. Mathematical models tested for the moisture ratio values of the mushroom

	Model name	Model equation	References
1	Newton	MR=exp(-kt)	Ayensu (1997)
2	Page	MR=exp(-kt^n)	Agrawal ve Singh (1977)
3	Henderson and pabis	MR=a exp(-kt)	Akpınar *et al.* (2006)
4	Midilli-Kucuk	MR=a exp(-k(t^n)+bt	Sacilik and Elicin (2006)
5	Wang and Singh	MR=1+at+bt^2	Wang ve Singh, (1978)
6	Two Term	MR=a exp(-kt)+bexp(-k$_1$t)	Soysal *et al.*(2006)
7	Two term exponential	MR=a exp(-kt)+(1-a)exp(-kat)	Sharaf-Elden *et al.* (1980)
8	Diffusion Approach	MR=a exp(-kt)+(1-a)exp(-kbt)	Toğrul and Pehlivan (2003)
9	Weibull distribution	MR=a-bexp[-(kt^n)]	Babalis et al.(2006)
10	Logistic	MR=a$_0$/(1+aexp(kt))	Alibaş (2012)
11	Alibas	MR=aexp((-kt^n)+(bt))+g	Alibaş (2012)

Results

The moisture ratio versus time curves for microwave drying of mushroom samples for different by microwave powers are shown in Fig.1. When the microwave powers of the sample increased, the time needed to achieve a certain moisture ratio decreased. For example, with drying, the time taken to reduce the moisture content of mushroom samples from the initial 93.4 %(w.b) to a final 9.27 %(w.b) was 30, 17, 11, 8 and 6 min at 180, 360, 540,720 and 900 W, respectively. It is obvious that the moisture ratio decreases more rapidly when the microwave power is increased. In other words, the increase in the drying microwave power resulted in a decrease in drying time. The decrease in drying time with increase in drying microwave power has been observed by Soysal (2004) for parsley, Wang and Xi (2005) for carrot slices and Gögüs and Maskan (2001) for olive pomace.

The statistical analyses results applied to these models in the drying process at 180, 360, 540, 720 and 900 W microwave powers are given in Table 2 for mushroom samples. The models were evaluated based on R^2, SEE and RSS. For all the drying conditions except 180W microwave power, the Alibas Model was the best descriptive model as shown in Table 2.

Table 2. Non-linear regression analysis results for microwave drying of mushroom

	180W			360W			540W			720W			900W		
No	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS
1	0.92	0.078	0.25	0.9134	0.084	0.1267	0.8949	0.101	0.1225	0.9016	0.103	0.0956	0.9033	0.106	0.0783
2	0.981	0.039	0.061	0.9991	0.009	0.0014	0.999	0.01	0.0011	0.9992	0.01	0.0008	0.9991	0.011	0.0008
3	0.96	0.056	0.125	0.948	0.067	0.0761	0.9316	0.085	0.0798	0.9327	0.09	0.0654	0.9279	0.099	0.0584
4	0.986	0.034	0.044	0.9998	0.004	0.0002	0.9998	0.005	0.0002	0.9996	0.008	0.0003	0.9998	0.006	0.0001
5	0.963	0.054	0.117	0.9933	0.024	0.0098	0.9906	0.032	0.011	0.9882	0.038	0.0114	0.99	0.037	0.0081
6	0.96	0.057	0.125	0.948	0.071	0.0761	0.9316	0.094	0.0798	0.9327	0.104	0.0654	0.9279	0.121	0.0584
7	0.92	0.08	0.25	0.9134	0.089	0.1267	0.8949	0.111	0.1225	0.9016	0.117	0.0956	0.9033	0.125	0.0783
8	0.92	0.08	0.25	0.9134	0.089	0.1267	0.8949	0.111	0.1225	0.9016	0.117	0.0956	0.9033	0.125	0.0783
9	**0.99**	**0.028**	**0.03**	0.9998	0.004	0.0002	0.9998	0.006	0.0003	0.9999	0.005	0.0004	0.9997	0.008	0.0003
10	0.882	0.097	0.37	0.9992	0.009	0.0012	0.9989	0.011	0.0012	0.9985	0.014	0.0014	0.9999	0.003	0.0004
11	0.988	0.033	0.039	**0.9999**	**0.003**	**0.0002**	**0.9999**	**0.003**	**0.0009**	**0.9999**	**0.003**	**0.0001**	**0.9999**	**0.004**	**0.0003**

SEE Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square

The Weibull Distribution model gives the highest values of R^2 and the lowest values of SEE and RSS for 180W. Based on the multiple regression analysis, the accepted models were as follows:

(2)

$$MR(a,k,n,b,g) = \frac{M - M_e}{M_0 - M_e} = \mathrm{a}\exp((\text{-}\mathrm{kt}^{\mathrm{n}}) + (\mathrm{bt})) + \mathrm{g}$$

(3)

$$MR(a,k,n,b) = \frac{M - M_e}{M_0 - M_e} = \mathrm{a} - \mathrm{b}\exp[-(\mathrm{kt}^{\mathrm{n}})]$$

Conclusions

Mushroom samples were dried using microwave drying. Drying periods lasted between 30 and 6 min for microwave drying depending upon the microwave output powers. The calculated values of moisture were compared with values predicted obtained from several thin layer equations; the Alibas Model was found to have the best fit except 180W. The Weibull Distribution model gives the highest values of R^2 and the lowest values of SEE and RSS for 180W.

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